spotted area for the year as a whole was decidedly smaller than for 1888, whilst towards the end of the year there was a marked tendency for spots to form in high latitudes, so that the mean distance from the equator of all spots was considerably greater than in 1888. As Professor Spoerer has pointed out, the appearance of spots in high latitudes usually indicates the commencement of a new cycle. If the present be an example of this rule, then the new cycle may be taken as commencing in June 1889; for there were no instances of spots in latitudes higher than 10° until June 29, when a spot appeared in S. lat. 40°. At the same time the mean daily spotted area increased notably, for whilst it was only 22·5 for the first six rotations of 1889, as against 89 for 1888, it rose to 202 for the four following rotations. On the other hand, however, there have been but few spots since this outburst came to an end, and it may eventually prove to have been a mere accidental and temporary revival, and not the true commencement of the new cycle. The course of the solar activity during the next few months can hardly fail to decide the point.

Totality of the Eclipse of 1889 *December* 22. By David P. Todd.

(*Communicated by Dr. Huggins.*)

I located the eclipse expedition just north of Cape Ledo, a bold bluff on the West African coast, about 75 miles south of Saint Paul de Loanda.

Totality was completely lost in clouds, but a brief general description of the apparatus for the total eclipse, and of the novel method of operating it, will not be inappropriate.

Three essentials were recognised: (1) A great variety of apparatus; (2) large-scale pictures of the corona; (3) perfect clockwork. I saw no better way to meet these conditions than by constructing an equatoreal stand sufficiently capacious to accommodate all, or nearly all, the photographic apparatus. Accordingly, a split polar axis was built of 6-inch wrought-iron tubes, about 11 feet long, and placed 2 feet apart. The whole was mounted English fashion, on massive cast-iron supports, capped with brass bearings. This was built by Mr. Saegmueller, of Washington, and I was fortunate in obtaining from him the loan of a very perfect and powerful clockwork to drive it. This latter was in process of construction for the great equatoreal refractor of the Denver Observatory, and I found its centrifugal governor, a triple-twist flexible steel spindle, to perform with the highest accuracy. Also, the means provided by Mr. Saegmueller for adjusting the polar axis into parallelism with the earth's axis proved to be very neat; and the adjustment was readily made so close that, with an hour's run of the clock, the declination error on the plate did not exceed 20″.

On this axis was mounted all the photographic apparatus for the total eclipse, and a high-power directing telescope to verify the pointing of the whole.

This comprised the following apparatus:—

1. Professor Pickering's reversing-layer spectroscope, for photographing a spectrum trail for 15 seconds both before and after second and third contacts.

2. Five photographic telescopes, the first a Clark $\frac{150}{8}$ doublet, twelve exposures, two being through a Carbutt orthochromatising screen; the second a Dallmeyer $\frac{38}{6}$ rapid rectilinear lens, sixteen exposures; the third a Dallmeyer $\frac{24}{6}$ rapid rectilinear lens, four exposures; the fourth a Ross $\frac{44}{5}$ portrait lens, eighteen exposures; and the fifth a Gundlach $\frac{22}{3 \cdot 75}$ aplanatic orthoscope, with one specially-prepared plate for the extreme outer corona, and other circum-solar objects.

3. Two catoptric telescopes by Brashear, with twenty-five exposures for each, the first having the ratio $\frac{33}{8}$, with the central 3 inches of the mirror sacrificed to the plate-holder; while in the second, $\frac{72}{8}$, the entire aperture was made available by setting the plate-holder at one side of the tube, and tilting the mirror slightly, as in the Herschelian form of mounting.

4. Five dioptric telescopes, with objectives uncorrected for the actinic rays, the first a Clark-Merz $\frac{96}{6 \cdot 4}$ objective, twenty-five exposures, of which five were made with the full aperture, and five each with apertures of 5, 4, 3, and 2 inches; the second, a Schroeder $\frac{22}{6}$ triple objective, one hundred exposures; the third, a Clark $\frac{72}{5}$ telescope, with the Sun's image enlarged to 4·5 inches diameter, four exposures; the fourth, a Spencer $\frac{36}{4}$ objective, eighteen exposures, divided among apertures varying from 1 to 4 inches; the fifth, a Clark $\frac{49}{3 \cdot 5}$ objective, twenty-five exposures. This latter instrument was intended to provide pictures precisely comparable with those of the eclipse of 1889 January 1, taken by Mr. Barnard; and, accordingly, the aperture of the objective was capped down to 1·75 inches.

5. Two flint-glass spectroscopes, and one quartz spectroscope, provided by Harvard College Observatory.

6. Two duplex cameras for photographing the polarisation of the corona, prepared by Dr. Wright, of Yale University.

7. A duplex telescope of 75 inches focal length, for coronal photometry, prepared by Professor Bigelow, who also got all the spectroscopes into readiness for the eclipse.

The finder, or directing telescope, was a $7\frac{1}{4}$-inch Clark refractor, with a high-power eyepiece.

In all, the apparatus mounted upon the polar axis embraced two mirrors and twenty-three objectives.

The operation of it by hand, as ordinarily, would of course have been impossible. My experience during the eclipse in Japan two years previously had suggested the desirability of automatic operation of all eclipse apparatus; and, as a result of much experimentation with different electric and pneumatic devices, I finally ventured to adopt the pneumatic valve system covered by the letters patent of Mr. Merritt Gally.

By means of this unique system, which has been largely employed in the automatic playing of musical instruments, a very small current of exhaust air—say of one-tenth inch diameter—is made to control an exhaust current very many times greater in volume.

A system of forty-eight such valves offered no difficulties of construction whatever, and was built in ten days' time, under the immediate personal supervision of the inventor. The tubes leading from the valve ports were of half-inch diameter. The control currents were governed by a succession of one-tenth inch apertures punched in a strip of paper about 9 inches wide and 7 feet long. This I wound upon the barrel of an ordinary chronograph, so that it should unwind at a perfectly uniform rate when the chronograph was set going. As the paper left the barrel, it passed over the "tracker," and was rewound upon a take-up roller. The whole was mounted over an exhaust organ-bellows, strongly built, and with springs of triple tension. This combined apparatus made a perfect pneumatic commutator, having forty-eight air currents in perfect control. In order to set any current in motion, it was only necessary to puncture the control sheet at a point whose x was equal to the time, and whose y corresponded to the number of the air port in the "tracker."

From the commutator, half-inch lead pipes were run to the position of the different mechanical devices which were to come into action during totality. Here they were connected with small pneumatic bellows of the ordinary V-pattern.

Each bellows, then, was so connected by appropriate mechanical movements that its collapsing thrust should perform the various sorts of work required, whether the operation of an exposing shutter, the revolution of a Nicol, the variation of available aperture, or the shifting of a photographic plate.

In such a variety of apparatus, it was impossible that one form of mechanical movement should suffice for the whole. The

requirements of some of the instruments were best met by shutters, which the pneumatic bellows held open against the action of a spring during the full length of the exposure, while others required that alternate actions of the pneumatic should open and close the shutter, or exposing-slide. This was easy enough; but the problem of changing the sensitised plates for new exposures turned out to be much more difficult, especially where a large number of exposures was required.

Where the plates were small and the exposures few, a sliding plate-holder was found to work best; here it was only necessary to fasten a ratchet to the back of the plate-holder, and then attach a pawl to the vibrating side of the bellows. But some of the plates were of the size 17 inches by 20, and they could not be advantageously managed in this way. I finally hit upon the idea of attaching them to a revolving crate or barrel, set in motion on its axis by means of a small weight fastened to a cord wound upon a pulley or wheel at one end. An escapement-wheel was then placed on the barrel, with detents equal to the number of plates, and each detent so adjusted that when at rest its corresponding plate lay in the focal plane of the objective. A very small pneumatic then sufficed as a pallet, or as a trigger to set off the mechanical device on the conclusion of each exposure. This simple movement was found to be sure of action, easy of construction, and to require a minimum of time for shifting the plates.

Also, the capacities of other devices for shifting plates were tried. At the focus of one of the smaller instruments a plate was set in a small frame sliding laterally in a frame of twice its own dimension, and this latter again sliding longitudinally in a shallow box of twice the dimension of the outer frame. By means of three pneumatic bellows, appropriately set and fitted with ratchet movements, every part of the sensitive plate was brought to the centre of the focal plane, and the exposure duly made.

For the reflectors it was found best to employ an endless chain or belt of plates, double-hinged together by means of continuous flexible tapes.

In order to test the utmost capacity of the automatic apparatus, and at the same time to furnish a large series of pictures of the same corona with a given instrument, a quick-acting lens was rigged with a long plate-barrel, sliding automatically forth and back in a frame rigidly attached to the tube. The barrel had ten plate strips upon it, and the ratchet movements gave ten exposures for each strip. In this manner one hundred exposures, from a half-second to two seconds long, were readily obtained with a single instrument.

In order to avoid the construction of a camera-box for each telescope, I adopted the plan of mounting the polar axis near the middle of a house, one end of which had a removable roof, while the other formed a dark room. The spaces between all the

instruments in the axis were readily stopped, and a partition athwart the house was built up underneath the axis and down from the rafters of the house. It was then a simple matter to connect the partition with a wooden frame around the exterior of the polar axis, by means of heavy opaque cloth secured to the partition and the frame, with sufficient slack to allow the necessary motion of the polar axis and all the instruments mounted on it.

It may be further stated that substantially all this apparatus for the automatic movements was devised, constructed, and tested at sea, during the voyage of the U.S.S. "Pensacola" from New York to Saint Paul de Loanda.

Notwithstanding the evident impossibility of securing any pictures of the corona, as a thick cloud stood nearly stationary over the Sun at the time of totality, the pneumatic commutator was brought into operation, and the control chronograph set going 15 seconds before the predicted time of second contact. The duration of totality was 190 seconds, and over 300 exposures were made. The automatic movements of exposing-shutters and the other apparatus in the uncovered portion of the house were apparent; while, in the absence of pictures on the plates, the accurate registration of the movable plate-holders was rendered certain by the subsequent examination of marks so placed upon the slides as to disclose any failure of the mechanism to act.

Two other instruments of the expedition were ready for use during the total eclipse, and deserve mention here on account of their unusual proportions; one of them—the 40-foot direct photo-heliograph—which Professor Bigelow's ingenuity had provided with a sand-clock of extraordinary precision, and a sliding plate-holder for obtaining three photographs of the inner corona during totality; and the other—a 20-inch silver-on-glass mirror, of 75-foot focus—kindly lent to the expedition by Professor Langley, and which was so mounted as to throw an image of the corona into a huge camera-box set upon a cliff which lay fortunately just beneath the Sun at the time of totality. Here a 10-inch image of the Sun came to focus, beautifully defined, and 20 × 24 inch plates of the highest sensitiveness were prepared for exposure. But during totality both these unusual telescopes were also rendered inoperative by clouds.